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Transverse Aortic Wall Tears in Infants After Balloon Angioplasty for Aortic Valve Stenosis:

Relation of Aortic Wall Damage to Diameter of Inflated Angioplasty Balloon and Aortic Lumen in Seven Necropsy Cases

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Aortic wall tears resulting from rupture of dilating balloons in infants undergoing transluminal balloon angioplasty have not been previously recognized. A 2 day old infant had percutaneous transluminal balloon angioplasty to dilate a stenotic aortic valve, and after multiple balloon inflations the balloon burst. The infant died 2 days after undergoing transluminal balloon angioplasty and at necropsy a circumferential, transverse aortic wall tear was found. To test the hypothesis that rupture of appropriately sized balloons results in similar aortic wall tears, six unfixed, intact infant aortas were subjected to transluminal balloon angioplasty at necropsy: two infants had balloon rupture with inflated balloon diameter similar to that of the aorta, two had balloon rupture with an undersized balloon and two had dilation with an oversized balloon. Transverse wall tears occurred in aortas with similar aortic and balloon diameters; no aortic wall damage occurred with rupture of undersized balloons, and aortic rupture resulted from the use of oversized balloons. Thus, intimal-medial tears in the infant aorta may result from balloon bursting during angioplasty when aortic and inflated balloon diameters are similar.

Transluminal balloon angioplasty has been increasingly accepted as a nonsurgical technique for dilation of stenotic arteries in the peripheral and coronary circulations (1–4) and more recently, in dilation of stenotic saphenous vein bypass conduits and pulmonary valves (5,6). Application of the balloon dilation procedure has also been extended to infants with congenitally stenotic cardiac valves or stenotic pulmonary or systemic vessels (7–11). Complications associated with transluminal balloon angioplasty in infants have included aortic perforation (12) and aortic dissection in operatively excised coarctation specimens (13) and in experimental coarctation models (14). Intimal and medial aortic tears have been previously reported (8) at the site of angioplasty in infants undergoing transluminal balloon angioplasty for aortic coarctation. This report describes transverse tears in walls of normal infant aortas associated with the rupture of an inflated angioplasty balloon, and describes a relation between aortic wall damage and the size of the inflated angioplasty balloon.

Methods

A 2 day old infant with aortic valve stenosis underwent percutaneous transluminal balloon angioplasty and subsequent surgical valvulotomy, but died 2 days later. A transverse, circumferential aortic wall tear observed at necropsy prompted us to test the hypothesis that transverse aortic wall tears may result from balloon rupture when the diameters of the aorta and the inflated angioplasty balloon are similar. Pertinent clinical and morphologic data on one necropsy patient (Case 1) with transluminal balloon angioplasty during life and six additional infants (Cases 2 to 7) with transluminal balloon angioplasty at necropsy are summarized in Table 1.

Case Reports

Necropsy Case 1. This patient was a full-term male born on March 15, 1983. A precordial systolic murmur was heard at 1 day of age with a normal cardiac silhouette on chest

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Table 1. Clinical and Morphologic Observations in Seven Cases of Necropsy Infants With Aortic Balloon Angioplasty

	Infant						
	Angioplasty During Life	Angioplasty at Necropsy					
Observations	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Age (days) at angioplasty	2	3	1	7	2	3	5
Sex	M	M	F	M	F	F	M
Clinical diagnosis	Aortic valve stenosis	RDS	RDS	RDS	RDS	RDS	RDS
Angioplasty data							
Catheter size (French)	5	5	5	5	5	7	7
Balloon inflation diameter (mm)	5	4	5	5	4	7	10
Balloon length (cm)	3	3	3	3	3	4	4
Pressure (atm) at balloon rupture	–	15	16	16	14	*	*
Inflated balloon diameter compared with aortic diameter	Similar	Similar	Similar	Smaller	Smaller	Larger	Larger
Clinical evidence of aortic damage	0	–	–	–	–	–	–
Necropsy data							
Diameter of aorta (mm)	5.2	4.0	5.0	6.5	5.5	4.5	5.1
Aortic wall damage							
None	0	0	0	0	0	0	0
Intimal tear only	0	0	0	0	0	0	0
Intimal-medial tear only (length of tear [mm])	+(16)†	+(3)	+(5)	0	0	0	0
Intimal-medial-adventitial tear (aortic rupture) (length of tear [mm])	0	0	0	0	0	+(14)	+(16)

*Aortic wall rupture before balloon bursting. †Extensive adventitial hemorrhage. F = female; M = male; RDS = respiratory distress syndrome; – = no measurement available.

radiography. One day later, the infant was tachypneic, dusky and had marked cardiomegaly and increased pulmonary vascular markings on chest radiography. He underwent cardiac catheterization and angiography on March 17 which disclosed severe aortic valve stenosis. Selective catheterization pressures (in mm Hg) were: left atrium, 20/10; left ventricle, 125/15 and ascending aorta, 55/35. The peak systolic gradient between left ventricle and aorta was 70 mm Hg with a cardiac index of 1.18 liters/min per m^2. Cineangiography disclosed a thickened and domed aortic valve with a small aortic anulus and a large patent ductus arteriosus.

Transluminal balloon angioplasty of the stenotic aortic valve was performed using a 5F polyethylene Dotter balloon catheter (Cook, Inc.) with a 5.0 mm inflated balloon diameter and a 3.0 cm balloon length. With the balloon across the aortic valve, several dilations were performed reaching high inflation pressures and bursting the angioplasty balloon. After balloon angioplasty, the peak systolic aortic valve gradient decreased 30 mm Hg (from 70 to 40; left ventricle: from 125/15 to 120/12; aorta: from 55/35 to 80/35), and an aortogram showed more rapid washout of contrast medium than before angioplasty. Aortic wall damage was not apparent on the postangioplasty aortogram. The infant had persistent metabolic acidosis and systemic hypotension and underwent open aortic valvulotomy a few hours later.

At operation, the aortic valve was bicuspid with one of two commissures open, but no other area of dilation injury. A large thrombus was attached to the anterior wall of ascending aorta at the level of the pericardial reflection (origin of right innominate artery). After aortic valvulotomy and ductus ligation, the infant remained severely acidotic and hypotensive despite inotropic agents. He died on March 20, 2 days after transluminal balloon angioplasty and open valvulotomy.

At necropsy, the bicuspid aortic valve had a small anulus, the cusps were mobile but thickened and the left ventricular walls were hypertrophied. A transverse, circumferential (16 mm) aortic wall tear was found in the aortic arch between the origin of the right innominate and left carotid arteries (25 mm above the aortotomy site and 30 mm above the aortic valve [Fig. 1]). Histologically, the intima and media had been separated, leaving only strands of adventitial tissue (Fig. 1C). Placing the same size catheter across the aortic valve, the transverse tear corresponded to the proximal junction of the balloon-catheter attachment (Fig. 2). In view of the surgical valvulotomy, necropsy assessment of injury of aortic valve angioplasty dilation was not possible.

Necropsy Cases 2 to 7. Six additional infants aged 1 to 7 days (three male and three female) underwent transluminal balloon angioplasty at necropsy within 1 hour of death (Ta-

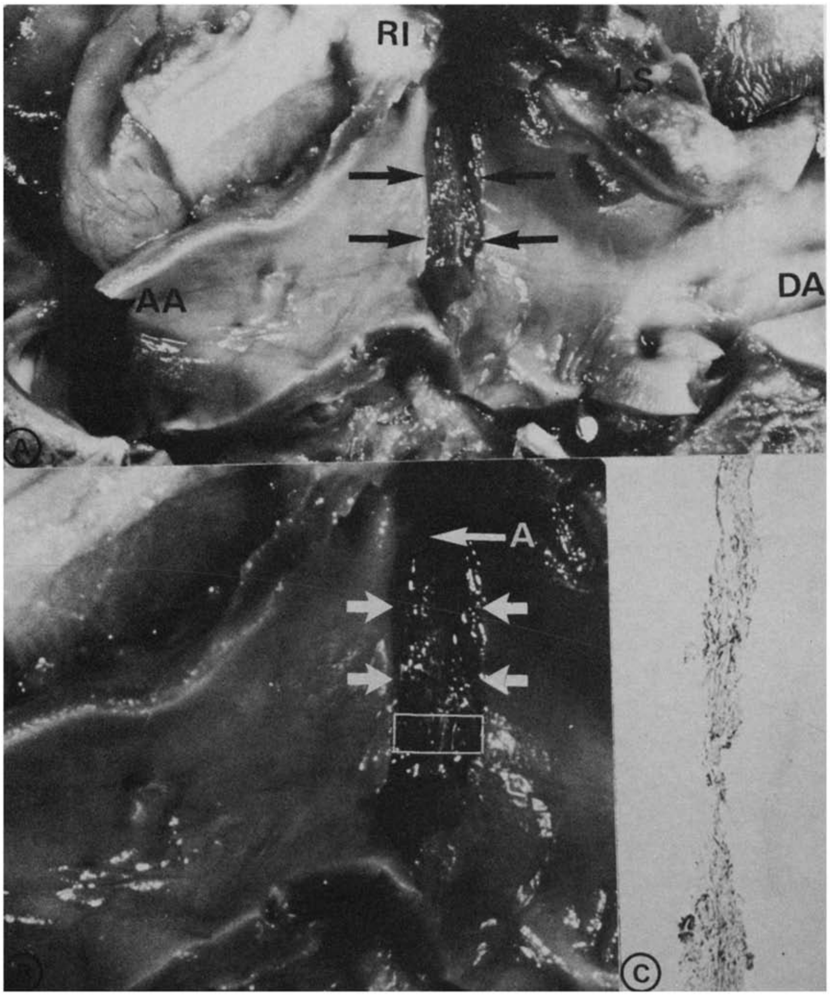

Figure 1. Case 1. Morphology and histology of aortic wall tear. **A**, Ascending aorta (AA) at the level of aortic arch showing a circumferential transverse tear (**arrows**). **B**, Close-up of an aortic tear (**arrows**) showing the remaining thin adventitial (A) layer of aortic wall. **C**, Photomicrograph of the **boxed area** in **B** showing only strands of the remaining adventitial tissue. DA = descending aorta; LS = left subclavian artery; RI = right innominate artery. (Elastic stain, magnification ×55, reduced by 32%.)

ble 1). All infants died from respiratory distress syndrome with severe hyaline membranes and all had a normal aorta. In each infant, the fresh, intact and unopened aorta and heart were isolated from the body and placed in normal saline solution to prevent loss of aortic wall elasticity. The external aortic diameter of the aortic arch-ductus junction was measured (in millimeters) and 1 mm was subtracted from this measurement to obtain an approximate aortic luminal diameter. Later measurements of the opened aorta from the same infants disclosed that this internal diameter approximation was within 1 mm of the actual luminal diameter.

Both 5F (Cook, Inc.) and 7F (Meditech, Inc.) polyethylene balloon angioplasty catheters with various balloon inflation diameters and lengths were inserted into the unopened infant aorta. The balloon was positioned in the aortic arch-ductus area in each patient, and inflated until the balloon burst (14 to 16 atm, Cases 2 to 5) or aortic rupture (Cases 6 and 7) occurred. Two infants (Cases 2 and 3) had a catheter chosen so as to have the inflated balloon diameter *approximate* (4 and 5 mm) the internal diameter of the aorta (Fig. 3); two infants (Cases 4 and 5) had a catheter chosen to have the balloon diameter *smaller* (< 6 mm) than the diameter of the aorta (Fig. 4) and the two remaining infants (Cases 6 and 7) had a transluminal balloon angioplasty with an inflated balloon diameter *larger* (> 6 mm) than the internal diameter of the aorta (Fig. 5). The latter two infants had aortic wall rupture before the balloon burst. Two additional infants had aortic angioplasty with an inflated balloon diameter similar to that of the aorta, in whom the angioplasty balloon was inflated to near maximal pressure without balloon rupture.

Results

Angioplasty balloon diameter similar to aortic diameter. Cases 1 to 3 had a maximally inflated balloon diameter similar to their respective aortic diameter (Table 1), and each had a transverse intimal-medial tear associated with rupture of the angioplasty balloon (Fig. 1 to 3). In each infant, the aortic wall tear was located near the proximal end of the balloon-catheter junction (Fig. 2). Histologic sections at the site of the aortic tears disclosed separation of a thin intimal layer and extensive separation of elastic

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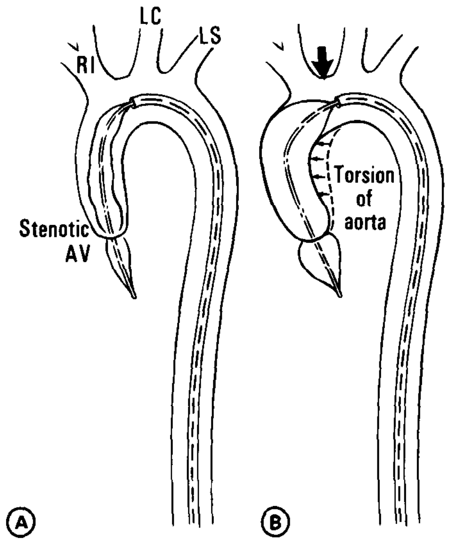
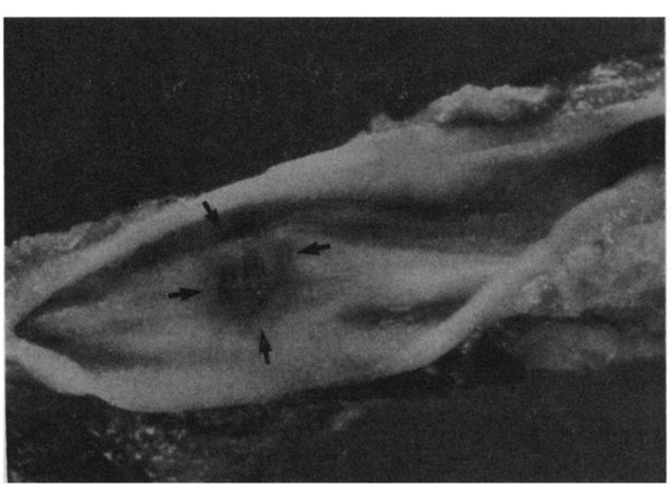


Figure 2. Case 1. Diagram showing the location of the balloon dilating catheter and the effects of balloon inflation on the position of the ascending aorta. **A**, Noninflated balloon across stenotic aortic valve (AV). **B**, The inflated balloon tends to displace (''straighten'') the ascending aorta toward the right (**small arrows**). The **large arrow** indicates the site of the circumferential transverse tear illustrated in Figure 1A. LC = left carotid artery; LS = left subclavian artery; RI = right innominate artery.

fibers in the medial layer. The adventitial layer was minimally involved in transluminal balloon angioplasty tears at necropsy (Cases 2 and 3), but extensively separated in Case 1 (Fig. 1C). The aortic wall tear produced during clinical dilation in Case 1 was longer, wider and deeper than the similar aortic tears produced in the infants (Cases 2 and 3) with necropsy dilation.

Figure 3. Case 2. Inflated balloon diameter similar to the aortic luminal diameter. Opened ascending aorta showing a transverse aortic wall tear after the bursting of an angioplasty balloon. The diameter of the inflated balloon and ascending aorta were the same (4.0 mm). Surrounding the tear is a reddish-brown abrasion collar (**arrows**), presumably caused by the effects of balloon bursting.



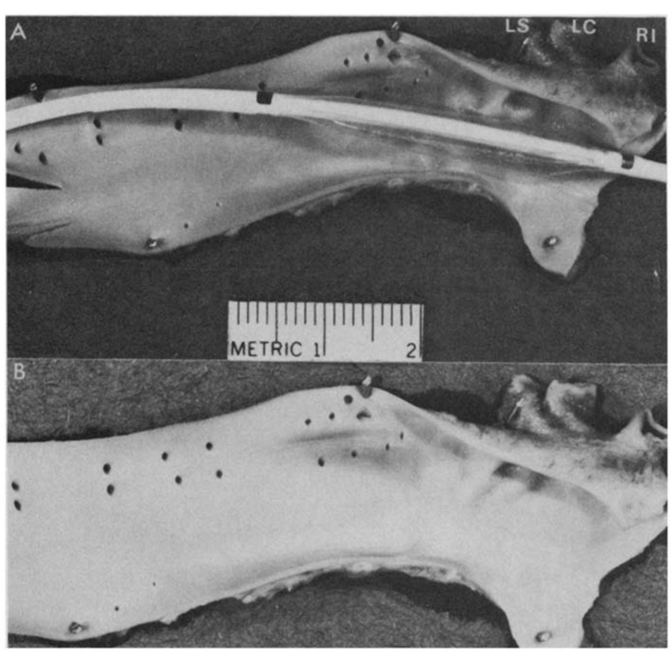
In two additional infant aortas, inflation of the angioplasty balloon to near maximal inflation pressure for 10 to 60 seconds without balloon rupture did not produce an aortic intimal-medial tear. Only with balloon rupture did transverse aortic wall tears result.

Angioplasty balloon diameter smaller than aortic diameter. Cases 4 and 5 had a maximally inflated angioplasty balloon diameter *smaller* than the aortic diameter (Table 1), and bursting of the balloon was not associated with aortic intimal, medial or adventitial damage (Fig. 4).

Angioplasty balloon diameter larger than aortic diameter. Cases 6 and 7 had a maximally inflated balloon diameter *larger* than the aortic diameter (Table 1) and inflation of the balloon resulted in aortic rather than balloon rupture (Fig. 5). The aortic rupture area was near the site of maximal balloon inflation.

Role of angioplasty balloon inflation diameter (Fig. 6). Rupture of angioplasty balloons with maximal inflation diameters *similar* to that of the aortic lumen was associated with transverse aortic wall tear, and rupture of balloons with maximal inflation diameters at least 1 mm *less* than the aortic diameter caused no aortic damage. Inflation of balloons with a diameter 3 mm or *larger* than the aortic luminal diameter was associated with aortic rupture before balloon bursting. Near maximal inflation of angioplasty balloons with diameters *similar* to that of the aorta but without balloon rupture did not produce aortic wall damage.

Figure 4. Case 4. Inflated balloon diameter smaller than the aortic luminal diameter. **A**, The position of the angioplasty balloon in opened ascending aorta. **B**, No aortic wall damage was created by balloon bursting. The diameter of the inflated balloon wsa 5.0 mm compared with an aortic luminal diameter of 6.5 mm. Abbreviations as in Figure 2.



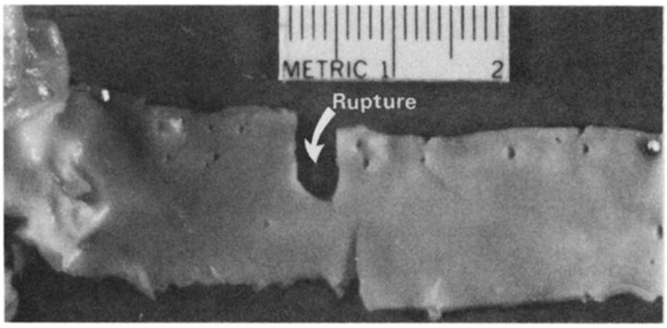


Figure 5. Case 7. Inflated balloon diameter larger than the aortic luminal diameter. The opened aorta shows the site of aortic rupture (**arrow**). The diameter of the inflated balloon was 10.0 mm compared with an aortic luminal diameter of 5.1 mm.

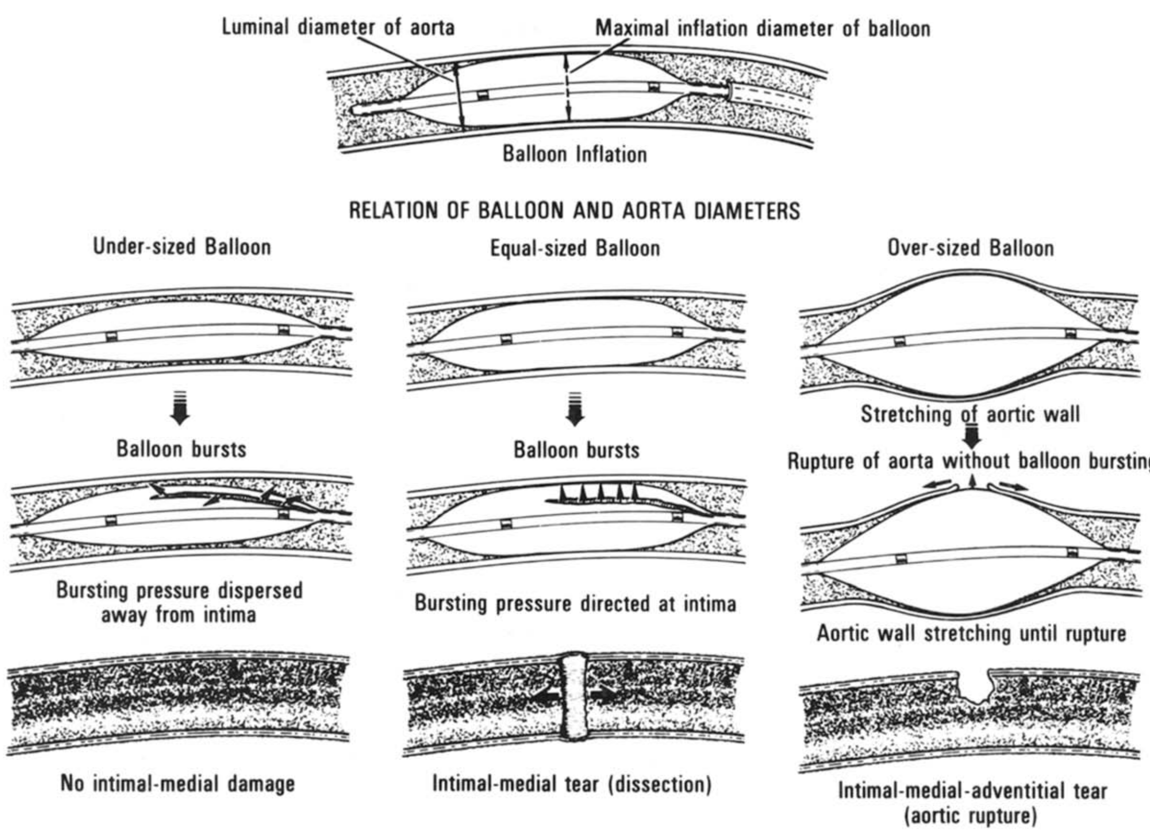
Discussion

Aortic wall tears during angioplasty. A 2 day old boy with severe aortic stenosis underwent transluminal balloon angioplasty that resulted in hemodynamic and angiographic improvement. Although the angioplasty balloon ruptured during maximal inflation, clinical and angiographic evidence did not indicate aortic wall damage. Despite the presence of a large thrombus on the external surface of the aortic wall at operation, aortic luminal damage was not discovered. Attempts to reproduce aortic wall damage with and without balloon rupture at postmortem transluminal balloon angioplasty on the normal aorta of six similarly aged infants using variable balloon and aortic diameters resulted in aortic wall tear from balloon rupture only when balloon and aortic luminal diameters were similar. Aortic wall tears could not be produced using similar sized balloons without rupture or using smaller balloons; aortic rupture resulted using larger balloons.

The intimal-medial aortic tears produced in aortic angioplasty at necropsy were smaller and shallower compared with the transverse tear in the patient undergoing clinical angioplasty. These differences may be related to the in vivo effects of fixed attachments of the aorta to adjacent tissues and vessels or to the effects of an intact vascular compartment, or both.

Transluminal balloon angioplasty of the aortic valve during life also may be associated with lateral displacement or slight "straightening" of the ascending aorta (Fig. 2) during balloon inflation. Although this aortic displacement may have contributed to the severity of the transverse tear in Case 1, the reproduction of similar tears at necropsy without in vivo aortic attachments indicates that the major aortic wall damage (that is, tears) resulted from balloon rupture itself. Although the mechanism of aortic tears from balloon

Figure 6. Diagram showing the relation of angioplasty balloon size, balloon bursting and aortic wall damage.



bursting is unknown, sudden release of inflated balloon pressure or its contents onto a closely adherent aortic wall may produce injury.

Potential consequences of transverse aortic wall tears. The thin remaining adventitial layer of the aorta found in Case 1 may have progressed to actual aortic rupture or pseudoaneurysm formation had the infant survived or maintained normal systemic pressures. Intimal-medial layer disruption from any cause is the morphologic forerunner of aortic dissection, aneurysm formation or rupture. The single previous report (12) of aortic wall rupture after transluminal balloon angioplasty for aortic coarctation was in a 7 day old infant who had perforation of the dilated aortic segment by a catheter or wire recrossing the dilated area. Lock et al. (14) made deliberate attempts to rupture the aorta of lambs, but rupture or perforation occurred only when dilating balloons had a diameter more than three times the diameter of the coarctation. These experimental results are similar to our necropsy data in Cases 6 and 7. Chronic aortic weakening, however, was not apparent in the experimental coarctation model, although several aortic walls could still easily be perforated with catheters (14).

Clinical results of aortic valve angioplasty. Lababidi et al. (11) recently reported successful balloon angioplasty in 23 children (aged 2 to 17 years) with congenital aortic valve stenosis. Angioplasty balloon diameters were chosen at least 1 mm *smaller* than the diameters of the aortic valve anulus. Aortic wall damage was not clinically recognized in any of the 23 patients despite balloon rupture in 8. Two patients underwent open valvulotomy, and aortic wall hemorrhage or intimal tears were not noted. The balloon-aortic diameter relation chosen for dilation in these children was similar to that in our necropsy Cases 4 and 5.

Differences between infant aortic angioplasty and adult coronary artery angioplasty. Coronary artery rupture has been reported during percutaneous coronary transluminal balloon angioplasty (15,16), and in at least one of these patients rupture was caused by the use of a balloon larger than the size of the coronary artery (16). To our knowledge, no reports exist of coronary dissection or rupture specifically related to bursting of an appropriately sized angioplasty balloon, despite the relatively common occurrence of balloon rupture in coronary angioplasty. A distinguishing difference, however, between infant aortas dilated in our study and adult coronary arteries and other vessels subjected to balloon angioplasty is the intimal thickness. In adults undergoing balloon angioplasty of stenotic vascular lesions, atherosclerotic plaques produce considerable intimal thickening, and any adverse effects on the vessel wall from balloon bursting theoretically could be "absorbed" or "cushioned" by the thickened intimal layer. In contrast, an infant aorta has very thin intimal layers free of atherosclerotic plaque, and any adverse effects of balloon bursting are transmitted directly to medial and adventitial layers. Although the major area of angioplasty damage in an adult vessel appears to be in the *intima* (17,18), the primary site of disruption in an infant aorta is in the *media*.

Implications. Although extensive transverse tears may not be detected clinically on post-transluminal balloon angioplasty angiograms (as in our Case 1), an aortic wall tear should be considered when angioplasty balloon rupture occurs, especially if balloon and aortic diameters are similar. Furthermore, if the patient is undergoing surgery for unsuccessful transluminal balloon angioplasty or for other reasons, the presence of overlying aortic wall thrombus should prompt a diligent search for an aortic wall tear. The use of smaller balloons and avoidance of balloon rupture when possible, and perhaps the use of stronger angioplasty balloons may prevent aortic wall damage in infants undergoing transluminal balloon angioplasty procedures.

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